THE BOX-OF-ROCKS EXPERIMENT (BORE): A SUBORBITAL EXPERIMENT PACKAGE FOR MICROGRAVITY REGOLITH SCIENCE AND TECHNOLOGY DEMONSTRATION. D. D. Durda[1] and, A. H. Parker[1], A. D. Whizin[2], M. Shoffner[1], and B. Pyke[1], [1]Southwest Research Institute 1050 Walnut Street Suite 300 Boulder CO 80301 (durda@boulder.swri.edu), [2]Southwest Research Institute 6220 Culebra Road San Antonio TX 78238.

Introduction: The investigations that comprise the various versions of the Box-of-Rock Experiment (BORE) payload take advantage of the minutes-long and exceptionally 'clean' microgravity conditions offered by the next generation of commercial reusable suborbital vehicles to address science and exploration questions directly relevant to ongoing and future NASA missions to small bodies.

Knowledge of the surface properties of small asteroids is important for relating astronomical observations of these objects to geologic 'ground truth', for understanding their relationships to meteorites, and for designing technologies and techniques for future robotic and human exploration, resource utilization, and impact hazard mitigation. The regoliths (the surface 'soil', composed of fragments of rock ground to various sizes by myriad impacts large and small) on these small bodies represent valuable natural laboratories for evaluating various models of their formation and evolution.

Unfortunately, many of the most interesting physical processes at play on these bodies and controlling the evolution of their regoliths are partially or completely masked in the 1-g environment in which we usually work and develop our 'intuitive' sense of how geologic processes work. *Physical experiments in actual microgravity conditions, such as those provided by suborbital flights, are a crucial component of research investigations at our disposal for exploring answers to these questions.*

Experiment Design and Configuration: The BORE experiment payload was developed, built, and flight tested under SwRI internal research and development funding and with participation in Blue Origin's Pathfinder Payloads flight program. The experiment has flown in various configurations with different objectives on both parabolic aircraft flights and suborbital spaceflights.

The original BORE configuration consisted of two transparent boxes, illuminated inside by an array of neutral white LEDs, enclosing two different types of rock samples that simulated a small asteroid's coarse regolith. Video cameras recorded the piles of rocks through the entire flight, but focused on examining their settling behavior during the onset of milli-g conditions during atmospheric entry of the vehicle. A secondary objective of the experiment was the derivation of block shapes from imaging to aid interpretation of spacecraft imagery of regolith blocks (*i.e.*, comparison of derived axes ratios from 2D projection in images to known true 3D axes ratios [1,2]). The BORE flight hardware as flight tested aboard the Zero-G parabolic aircraft and as installed in its Blue Origin payload container for its April 2016 spaceflight are shown in Figs 1 and 2.

Figure 1. BORE payload hardware (large box in the upper left portion of the image) during free-float microgravity flight testing aboard the Zero-G aircraft in November 2013.

Figure 2. Closeout photo of the BORE flight hardware before its April 2016 suborbital spaceflight aboard Blue Origin's New Shepard vehicle.

The first flight of BORE was highly successful, achieving all its proof-of-concept and experiment objectives. Figure 3 shows a frame from video data from the experiment with overlaid motion tracking information used to determine regolith fragment settling rates and coefficient of restitution during low-speed collisional interactions.

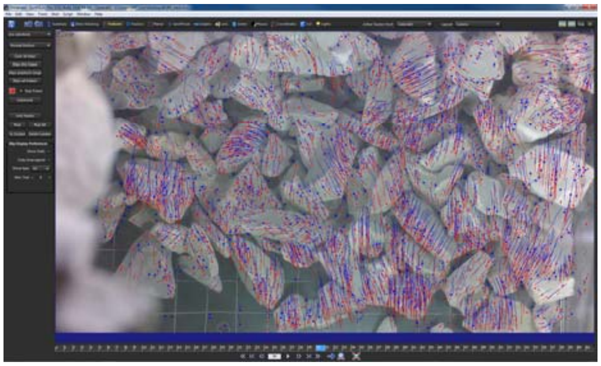

Figure 3. Video frame from BORE's April 2016 spaceflight showing motion tracking image analysis of the settling motion of regolith fragments during the onset of milli-g conditions during atmospheric re-entry of the Blue Origin New Shepard Crew Cabin.

BORE II flew aboard Blue Origin's New Shepard vehicle again in October 2020, conducting a highly successful evaluation of a novel regolith sampling and surface anchoring technique to advance exploration and ISRU technology BORE II was effectively a reflight of the BORE experiment payload, leveraging our successfully flight-proven BORE payload hardware so that the experiment boxes hold vacuum (~0.5 to 1 Torr) and including a more realistic regolith simulant composed of minerals appropriate to actual asteroids (an analog for Orgueil, a primitive CI carbonaceous chondrite) and a realistic/complex size distribution of fragment sizes. Figure 4 shows the BORE II payload hardware installed in its Blue Origin payload container for its October 2020 spaceflight. See the companion abstract for this conference by Parker et al. for a detailed description of the experiment and results.

Figure 4. Closeout photo of the BORE II flight hardware before its October 2020 suborbital spaceflight aboard Blue Origin's New Shepard vehicle.

Future Experiments and Tech Demonstrations: The BORE design is intended to allow flexibility for future experiment configurations and the inclusion of new, additional hardware for various technology demonstrations involving collection and interaction with regoliths in micro- and low-gravity conditions. With BORE II demonstrating very efficient magnetic sampling of chondritic regolith material, the BORE III payload is planned to demonstrate magnetic grappling and seismic coupling to a chondritic surface in support of future seismic measurements on small asteroids, with specific and timely application to an Apophis mission taking advantage of the once-in-a-millennium opportunity afforded by the 2029 very close approach of the near-Earth asteroid. Such measurements would allow determination of the internal structure of an asteroid, a key knowledge gap for asteroid science and for PHA mitigation technologies. Future plans include an enhanced vacuum system design, improved camera performance, and completion of a rigorous vibration validation to off-nominal vehicle flight conditions (which removes secondary sealing requirements, simplifying and speeding final integration at the launch site), paving the way to allowing faster pump down to deeper vacuum levels that are required for enabling more realistic charging and plasma environments to be simulated in future flights. This is an important step for understanding the magnetic coupling and anchoring of the sensors/samplers. A follow-on flight of BORE II in its present configuration with at least one of the vacuum chambers containing an ordinary chondrite regolith appropriate to the Sq spectral type of Apophis will provide key data for informing BORE III design and a significant risk buy down for BORE III science and technology demonstration objectives.

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References: [1] Michikami, T., et al. (2010) *Icarus, 207*, 277–284. [2] Michikami, T., et al. (2019) *Icarus, 331*, 179–191.